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AN INVESTIGATION OF LARGE-SCALE UPPER-AIR FLOW AS A MEANS OF EXPLAINING THE TELECONNECTIONS BETWEEN LONG-TERM GLACIER MASS BALANCE VARIATIONS ON MOUNT LOGAN AND LONG-RANGE SPATIALLY-AVERAGED PRECIPITATION VARIATIONS IN THE PRAIRIE/STEPPE REGIONS OF NORTH AMERICA AND EURASIA (U.S.S.R.)

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MANAGEMENT PERSPECTIVE

Weather and climate are our greatest natural resources. Variations of climate influence the economy and the environment and have a potential impact on the hydrological cycle. To have an inventory of spatially-connected historical climate variations is an important pre-requisite for assessing the impact of climatic change on the Canadian Prairies. Furthermore, any climatic variation model requires historical hydrological and climatic data against which it can be tested.

This study shows that historical variations of the Canadian climate sometimes occur simultaneously with climatic variations in distant regions, but sometimes not. It represents an important step towards establishing periodic teleconnections (cross correlations) between the net precipitation series from Mount Logan and those from the Steppe and Prairie-Steppe areas of the Northern Hemisphere.

PERSPECTIVE DE GESTION

Le temps et le climat sont nos plus importantes ressources naturelles. Les variations du climat influencent l'économie et l'environnement et peuvent avoir une incidence sur le cycle hydrologique. Un inventaire des variations historiques du climat reliées les unes aux autres dans l'espace constitue une conditions préalable importante pour l'évaluation des répercussions de variations climatiques dans les Prairies canadiennes. De plus, la mise à l'épreuve de tout modèle des variations climatiques exige de disposer de données historiques sur l'hydrologie et le climat.

Cette étude montre que les variations historiques du climat canadien se sont parfois manifestées simultanément à des variations climatiques dans des régions éloignées, mais que ce n'est pas toujours le cas. Elle constitue une étape importante en vue de l'établissement de téléconnexions (corrélations croisées) entre la succession des précipitations nettes pour le mont Logan et pour les régions du steppe et de prairie-steppe de l'hémisphère nord.

ABSTRACT

A significant positive correlation has been found to exist between the annual net mass balance time series obtained from Mount Logan, Yukon Territory and the areal mean of the November-March precipitation from the Steppe and Forest-Steppe region of the central U.S.S.R. between 1900 and 1970. This apparent cross correlation ("teleconnection") might be due to comparable large-scale atmospheric air flow patterns and precipitation processes within the two regions during the precipitation-producing seasons either in or slightly out of phase. There has also been a significant positive correlation discovered between Mt. Logan time series and comparable time series for the Canadian Prairies and Beijing, China between 1900 and 1970. Since the physics behind teleconnections is still not fuly understood, it is necessary to make the relevant associations on an empirical basis.

RÉSUMÉ

Une corrélation positive significative a été constatée entre la succession chronologiques des bilans massiques annuels obtenus au mont Logan (Territoire du Yukon) et la moyenne surfacique des précipitations de novembre à mars pour la région de steppe et de forêt-steppe du centre de l'U.R.S.S. entre 1900 et 1970. Cette apparente corrélation croisée ("téléconnexion") pourrait être attribuable à des configurations de la circulation atmosphérique à grande échelle et à des processus de précipitation comparables dans les deux régions pendant les saisons produisant des précipitations, soit en coïncidence ou avec un léger déphasage. Une corrélation positive significative a également été établie entre la succession chronologique pour les prairies canadiennes et Beijing, en Chine, entre 1900 et 1978. Puisque la physique de ces téléconnexions est encore mal comprise, il est nécessaire d'établir les associations pertinentes de manière empirique.

TABLE OF CONTENTS

	Page
Introduction	1
Description of the long-term mean 50 KPa contour geometry.	6
Harmonic wave climatology of the Mt. Logan region.	10
Component wave conditions over the Soviet Steppe and Wooded-Steppe region	20
Future work.	26
Acknowledgements	27
References	28

TABLES

1.	Structure of the 7 decade data coverage.	11
2.	List of U.S.S.R. meteorological stations	20

ILLUSTRATIONS

1.	Time series diagrammes	2
2.	Mount Logan ice core D power spectrum on precipitation	5
3.	30-year mean monthly 50 KPa heights along 60°N, 1949-1978.	7
4.	Long-term mean 50 KPa heights, 40°N.	8
5.	Mean monthly amplitudes and phase angles, wave Nos 1-4	12
6.	Phase angles and amplitudes for wave No.2 at 60°N, 1946-1983	15
7.	Phase angles and amplitudes for wave No.3 at 60°N, 1946-1983	16
8.	Phase angles and amplitudes for wave No.4 at 60°N, 1946-1983	17
9.	Resultant amplitudes of the first 4 and 8 mean monthly harmonics	18
10.	Long-term mean 50 KPa heights for the Mt. Logan region	19
11.	Vegetation types of the World.	21
12.	Steppe and Wooded-Steppe regions of Eurasia.	22
13.	Situation of the annual long harmonic waves with respect to Mt. Logan and the Steppe-Prairies of the Northern Hemisphere	24
14.	Monthly mean distribution of the long component waves with respect to Mt. Logan and the Steppe Prairies of the Northern Hemisphere along 2 Latitudes.	25

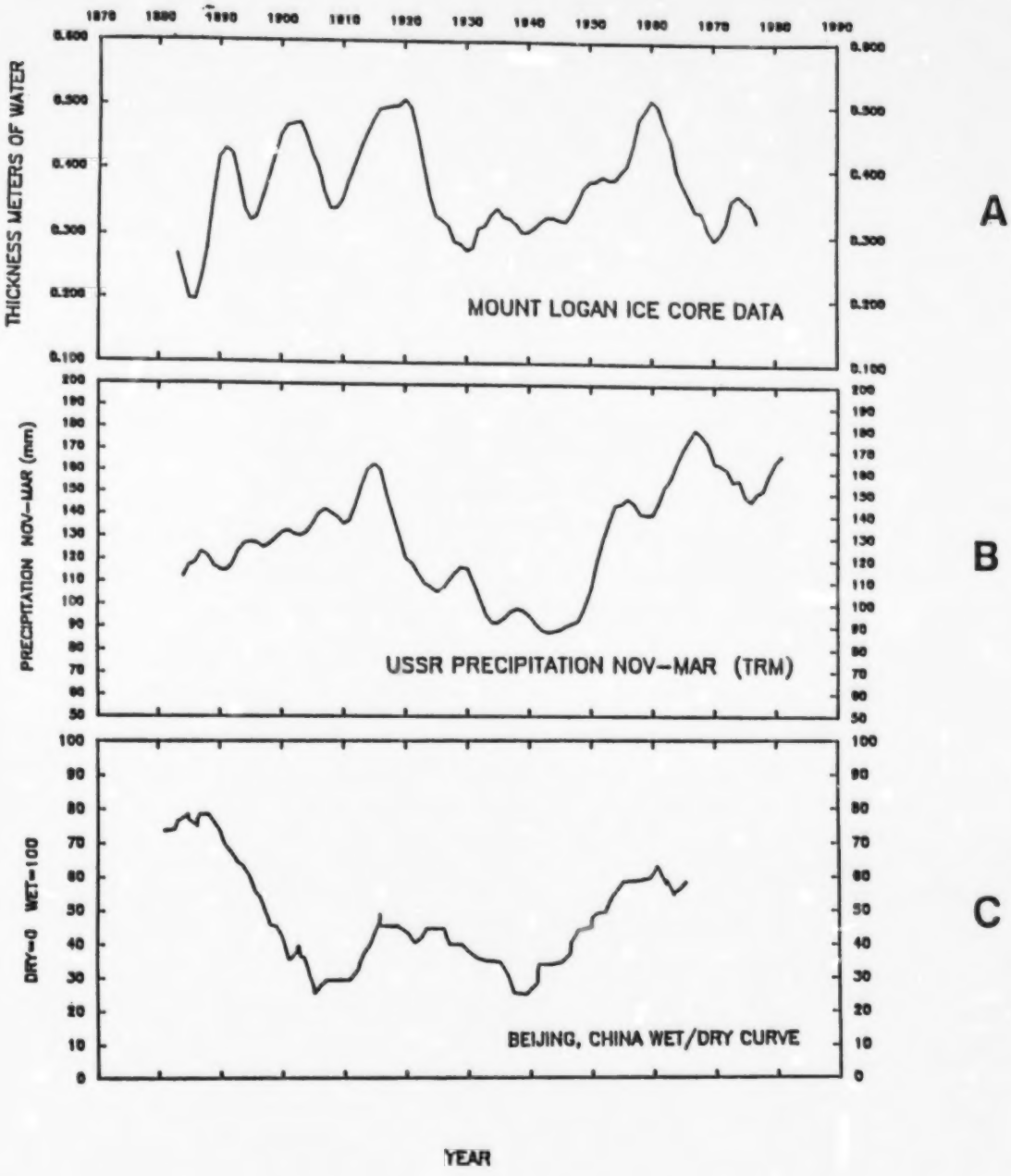
INTRODUCTION

A significant positive correlation of r=.74 has been found to exist between the annual (net) mass balance time series obtained from Mt. Logan, Yukon Territory (60°37′N, 141°30′W, 5340 m a.s.l.) (Holdsworth, unpublished) and the areal mean of the November-March precipitation from the Steppe and Forest-Steppe (Wooded or Prairie-Steppe) region of the central U.S.S.R. between 1910 and 1964 (Budyko, 1977). This is shown in Figure 1. The Mt. Logan time series have been low-pass filtered with a 7-year triangular filter. We have not yet attempted to lag the series or to look at its fine detail in case this is just local "noise". The apparent cross correlation (or "teleconnection") might be due to comparable large-scale atmospheric air flow patterns and precipitation processes of the two regions during the precipitation-producing seasons either in- or slightly out-of-phase. The concept of "teleconnection" implies (beside a significant cross correlation between 2 time series) an "apparent interconnection of the atmospheric circulation between large-scale pressure anomalies" (Shabbar, 1985). It should be emphasized that annual net precipitation at Mt. Logan and the winter season precipitation in the Steppe region of the U.S.S.R. are involved in this comparison simply because this is how both data sets were originally presented. The major part of the total annual precipitation of the two regions could have fallen in different seasons. For the Soviet Union Steppes, maximum precipitation occurs in the summer; for Mt. Logan it is probably skewed towards fall and winter.

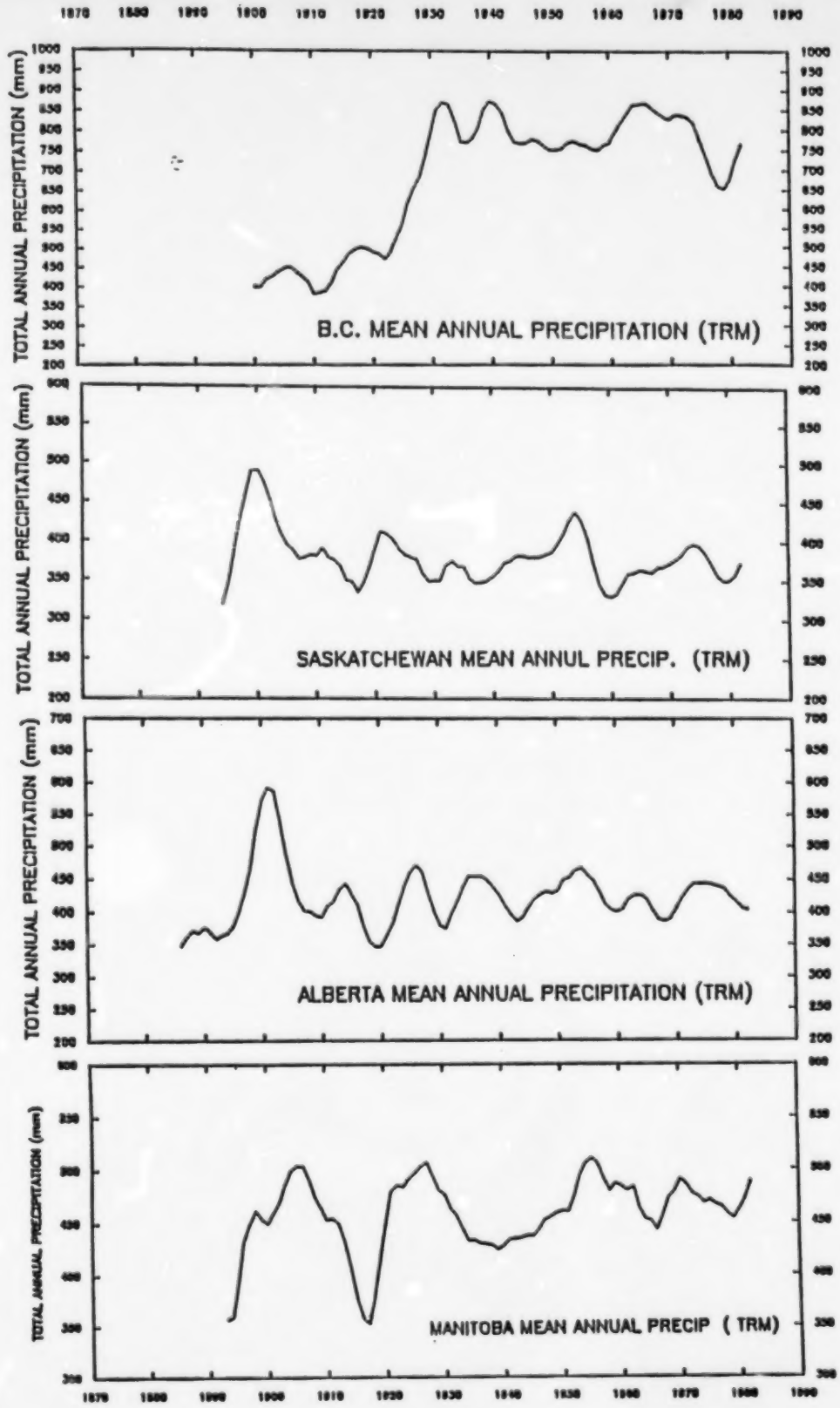
We can postulate that during the last century the long-term mean monthly large-scale atmospheric circulation patterns and hemispheric planetary-wave geometries for the two regions might have been similar but not necessarily on an individual monthly mean basis (Namias and Cayan, 1981).

We have also, subsequently, discovered a (significant) positive correlation between the Mt. Logan time series and comparable time series for the Canadian Prairies (Manitoba - 5-yr lag: r=.38, Saskatchewan - 0 lag: r=.19, Alberta - 5-yr lag: r=.18) and Beijing, China (r=.3) (Hameed et al. 1983) between 1920 and 1960 (Figure 1).

Figure 1. Time Series Diagrammes



Composite 7-year triangular running mean (TRM) diagramme of the annual net mass balance time series from Mt. Logan, Y.T., and the area mean of the November-March precipitation from the Steppe and Forest Steppe region of central U.S.S.R. 21-year running mean of Beijing wet and dry indices and the 10-year area running mean annual total precipitation of the western Canadian provinces.


TOTAL ANNUAL PRECIPITATION (mm)
B.C. MEAN ANNUAL PRECIPITATION (TRM)
SASKATCHEWAN MEAN ANNUL PRECIP. (TRM)
ALBERTA MEAN ANNUAL PRECIPITATION (TRM)
MANITOBA MEAN ANNUAL PRECIP (TRM)
YEAR

D

E

F

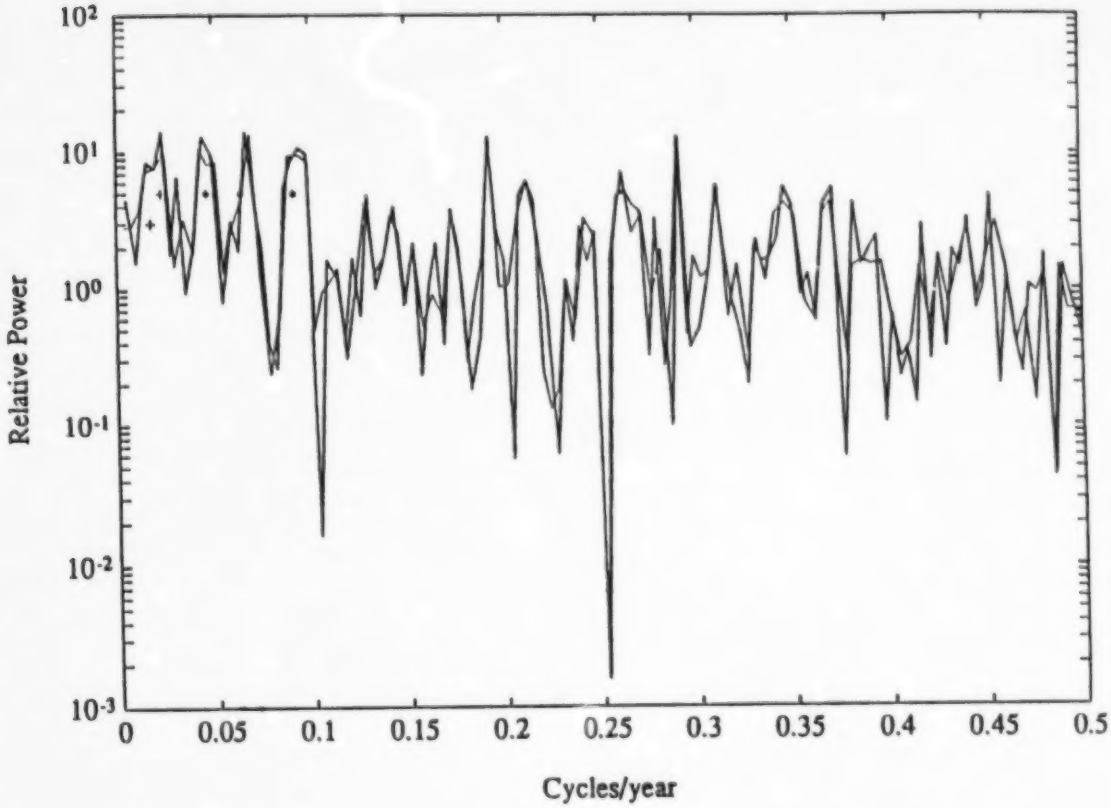
G

Some preliminary observations can be made about the inter-relationships between the curves shown in Figure 1. The 1885 low point of the Mt. Logan curve coincides with a low only in the Alberta and Manitoba curves. The 1900 Mt. Logan peak compares well with a peak in the Alberta and Saskatchewan curves. The 1910 Mt. Logan low point coincides with a low in the U.S.S.R. Steppe, Beijing, B.C. and Alberta curves. The 1920 Mt. Logan peak is in phase with Saskatchewan and Manitoba (1920-25). The 1930 Mt. Logan low point coincides with a similar feature in Saskatchewan and Alberta. The 1940 low point can be seen at Mt. Logan, in the U.S.S.R., Beijing, and Manitoba, whereas in Alberta and Saskatchewan it is slightly phase shifted. The second order 1952 ± 1 peak coexists in the Mt. Logan, U.S.S.R., Beijing, Alberta, Saskatchewan and Manitoba curves. The prominent 1960 peak at Mt. Logan is visible only on the Beijing curve and possibly on the Manitoba curve where it appears to be truncated. On most of the curves (except B.C.) the great drought of the 1930's to 1940's may be seen. In B.C., this period was the wettest, indicating that Pacific air moisture was depleted on the west coast before reaching the interior, mainly caused, we assume, by blocking processes. The preceding observations show the presence of a pronounced decadal scale variance and the interaction of waves of fairly close periodicity (e.g. 11, 15 years). (Figure 2 is a power spectrum of a 204-yr time series of Mt. Logan precipitation where periodicities of 10.9, 15, 21.3 and 55 years are apparent).

To examine these apparent teleconnections with more precision the long-term surface precipitation records for the regions involved should first be updated and, if possible, corrected for gauge changes; then spatially averaged according to some appropriate climatic zoning and area weighting scheme. The correlation between spatially-averaged instrumental surface data and the net annual mass balance of the single Mt. Logan site at the 50 KPa level must also be explained.

Initially, the Fourier components of the 50 KPa long-term mean contour heights will be examined to see if they can provide a possible link to teleconnections in the large-scale atmospheric circulation patterns. The long-term mean zonal harmonics are regarded as defining semi-permanent or quasi-stationary circulation centres. They might exert some influence on the processes

Figure 2. Mount Logan Ice Core D Power Spectrum on Precipitation



Fast Fourier Transform power spectrum of the Mt. Logan ice core precipitation time series, using data from 1777-1980 A.D. The higher frequency peaks may correspond to ENSO events. Peaks marked with an asterisk are respectively 10.9, 15, 21.3 years and the peak marked with crosses has a period of about 52 years.

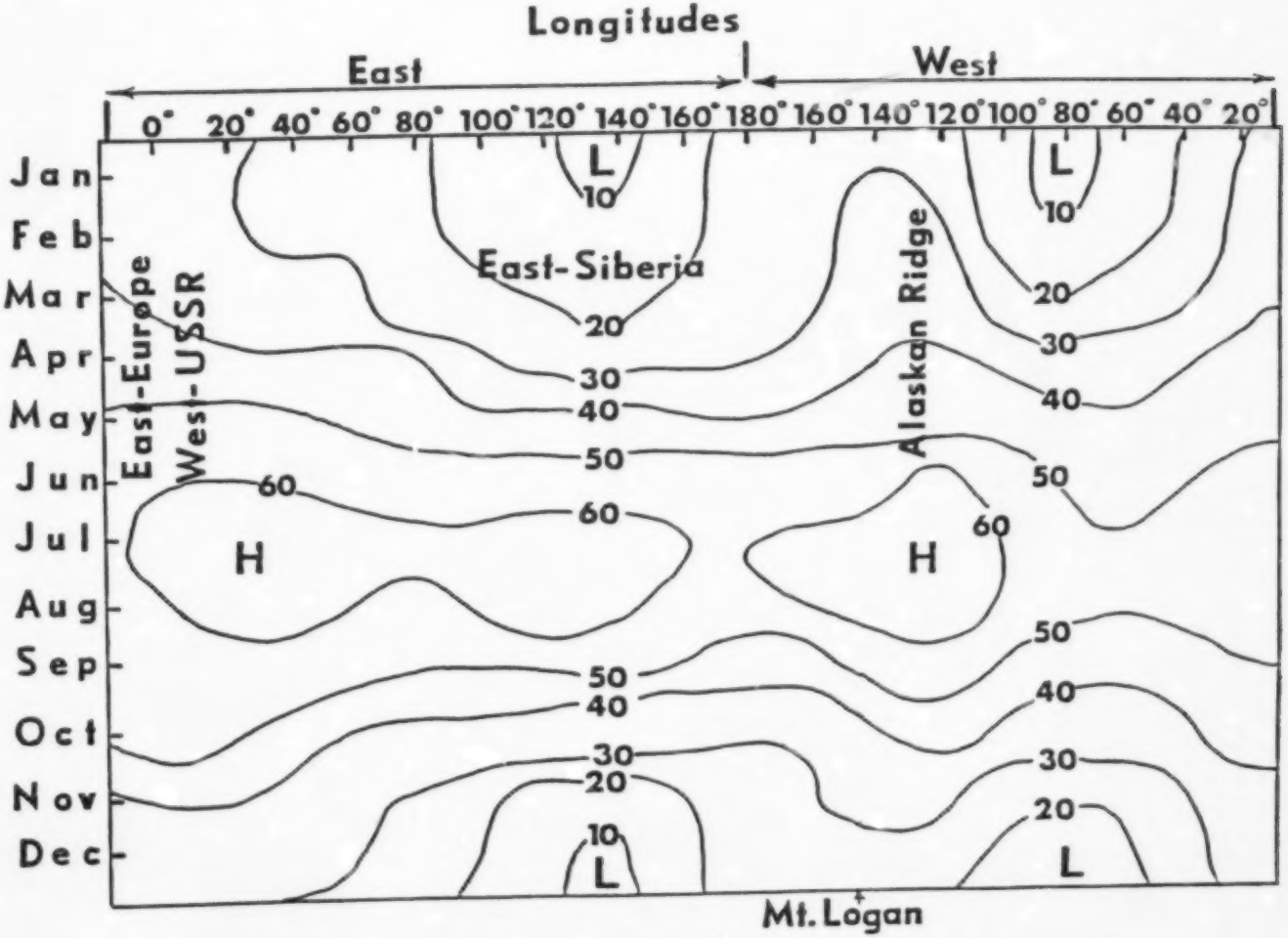
producing the observed teleconnections (Reiter, 1983). The Fourier statistics will be used to establish an empirical description of the teleconnections. Clearly, this is a problem that will ultimately be solved using atmospheric GCM's in which there is full coupling between the atmosphere and the oceans and in which there is a realistically integrated hydrological component. Such modelling is quite beyond our scope and may only be reached in Canada in approximately 2-years time.

There is considerable literature on teleconnections for a range of climatic variables (one of which is precipitation) and between combinations of these parameters. The literature is far too extensive for us to quote all the relevant papers (one of which is Reiter, 1983) but we detect in these papers a singular lack of development of the physics of the teleconnections, an idea that also seems to be implied by Lindzen (1986). However, there is a very well developed literature coverage on planetary wave dynamics and blocking (e.g. Tung and Lindzen, 1979; Austin, 1980 and Colucci *et al.*, 1986). It seems logical to assume that the physics of the teleconnections is tied directly into this field of research and we are tentatively making that association on an empirical basis.

DESCRIPTION OF THE LONG-TERM MEAN 50 KPa CONTOUR GEOMETRY

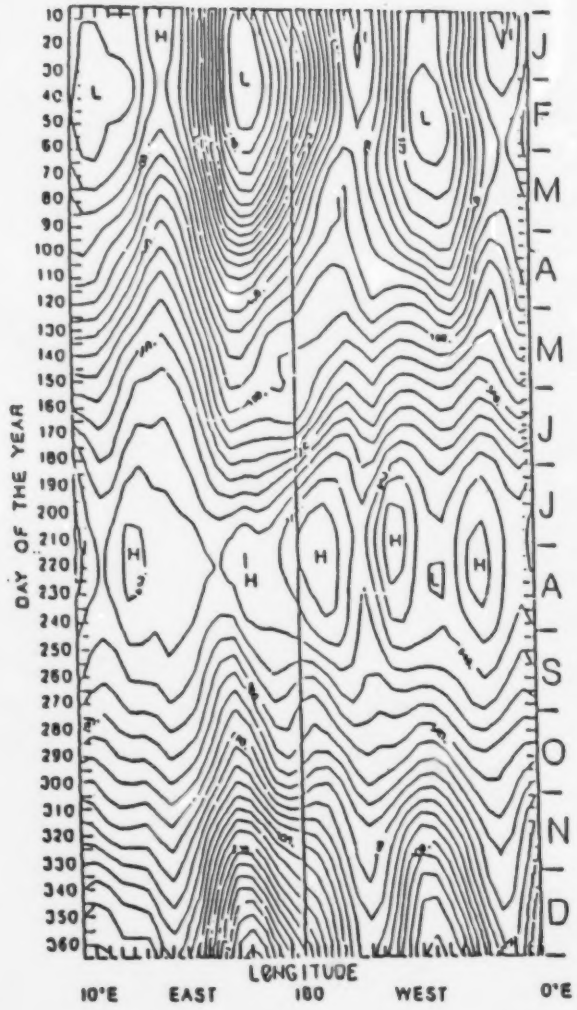
Because the Mt. Logan ice-core drilling site is situated in the mid-troposphere (estimated 50 KPa level) where quasi-geostrophic flow is normally assumed to occur as deduced from the results of pilot balloon studies (Benjey, 1969), large-scale teleconnections within the atmospheric circulation will be investigated using the 50 KPa surface topographies. The 50 KPa heights were extracted from the monthly mean 50 KPa charts (Harley, 1980) along latitude 60°N (Figure 3). Figures 3 and 4 are a one-dimensional representation of the 50 KPa mean monthly heights along the 60th and 40th parallels. Note that these figures are tables of the mean monthly contour heights along the respective latitude circles. Isoline patterns, superimposed on these tables, demonstrate the contour height monthly variations during the course of a year in the east-west direction. Since the monthly rows of Figures 3 and 4 were not obtained simultaneously, the isoline patterns superimposed on them cannot

Figure 3. 30-year Mean Monthly 50 KPA Heights along 60°N, 1949-1978



The last zero and the preceding "5"s are omitted from the contour labels.
The value "60", for example, stands for the 5600 GPM height.

Figure 4. Long-term Mean 50 KPa Heights, 40°N



Longitude sections of the 50 KPa pentad mean heights at 40°N. Isopleths are drawn for every 20 gpm as anomalies from 5200 m. Julian days are given along the left-hand side. The ordinate indicates the end of the pentad periods. Tic marks along the abscissa are for each 10° longitude. Isolines are the annual averages of the period, January 1946 to 28 February 1979.

be considered as indicators of geostrophic flows but only as the monthly pattern changes along the selected parallels.

The long-term (1949-1978) mean contour height distribution at 60°N (Figure 3) reveals that the 60°N contour height profile is characterized, during the summer, by a sequence of ridges and troughs in approximately a 3-wave pattern, such that:

a) The Alaskan ridge persists throughout the whole year.
b) The E. Atlantic - W. European ridge is less pronounced and shifts from 20°W in winter to 40°E in summer.
c) The E. Asian ridge at 120°E in summer is replaced by a trough in winter.

The November-December zonal patterns reveal that the ridges at about 140°W and 40°E are approximately 180° apart, suggesting a component from planetary wave number 2. In January-February the Alaskan ridge at 140°W and the East-Atlantic and West-U.S.S.R. ridge between 20°W and 20°E are 120° apart. This distribution indicates a component from wave number 3. Assuming that the first 8 harmonics could explain 100% of the total based on the variance, a simple calculation reveals that only the first 4 waves were dominant at 60°N throughout the year. In fact, the first 3 harmonics combined usually explain 90% of the total spatial variance, and wave number 2 and 3 combined explain about 60%. It appears that these two waves as well as Number 4 (see Austin, 1980) may hold the key to unravelling the physical basis for the observed teleconnections, through the occurrence of atmospheric blocking (Knox, unpublished) the centres of which are closely related to the geometry and dynamics of the ultra-long planetary waves. Egger *et al.* (1986) have shown that the blocking highs in the Northern Hemisphere are concentrated between 45°N and 65°N which is exactly the zonal band in which we observe the precipitation teleconnections.

From January to March, the 60°N profile displays the strong East Asian trough (140°E), the Alaskan ridge (140°W) and the North-East Canada trough (80°W).

The longitude-time distribution of the contour values at latitudes other than that of Mt. Logan can of course be quite different. Figure 4, for example, depicts the 50 KPa long-term mean (1946-1979) contour height distribution as

calculated by Reiter and Westhoff (1981) for 40°N. This figure also shows maxima from July to August 20° south of Mt. Logan. The winter ridges at the 75°E, 150°W and 30°W longitudes are respectively 75°, 180° and 105° displaced from the Mt. Logan meridian. In other words, the 40°N pattern during winter time differs significantly from that at 60°N, and the 40°N summer pattern shows more detail than the 60°N pattern.

It is well known that certain dynamic and thermo-dynamic processes give rise to semi-permanent pressure profiles. These processes are essential parameters in precipitation forecasting models. Positive vorticity and thickness advection take place on the west side of the 50 KPa contour ridges or the east side of the troughs. Accordingly, precipitation tends to occur preferentially on the westward sides of the upper air ridges, whereas subsidence and clearing take place on the east sides of ridge waves. Therefore, ridges of wave components with phase angles significantly less than 140°W, that crest downstream say 1/8 to 1/4 wave length, should be associated with more precipitation to the Mt. Logan region than ridges with phase angles in the vicinity of 140°W. Applying this argument on an inter-annual time scale, it is evidently possible to explain some of the major modulations in the sub-decadal time scale precipitation series (Figure 1) by corresponding inter-annual shifts in the major ridges of wave components. In addition, the intensity of ridging (or troughing), as measured from amplitude data, may be important in modulating the precipitation time series shown in Figure 1.

During the forthcoming discussion, more light can be shed on the spatial and temporal distribution of the large-scale and long-term mean quasi-stationary contour features and their related geostrophic flow structure around the Mt. Logan and Soviet Steppe regions on the basis of the long-wave components of the 50 KPa geo-potential heights.

HARMONIC WAVE CLIMATOLOGY OF THE MOUNT LOGAN REGION

For a first approximation of the harmonic wave climatology of the Mt. Logan region, only a general analysis is attempted. Guided by the most convenient set of available data, the 10-year averages of the monthly Fourier statistics

with 5-year overlap were considered. In this data set, decadal average monthly data were available from 15°N to 80°N and for wave numbers from 1 to 8. The data sets are listed for amplitudes and phase angles. The amplitudes indicate the positive deviations from the zonal means. Averages of the monthly mean amplitudes and phase angles of seven decades were obtained from the Atmospheric Environment Service of Environment Canada (Shabbar and Knox, 1987). The exact coverage of the seven time periods is shown in Table 1. Phase angles refer to the longitude of the first ridge east of the Greenwich meridian.

Table 1. Structure of the seven decade data coverage

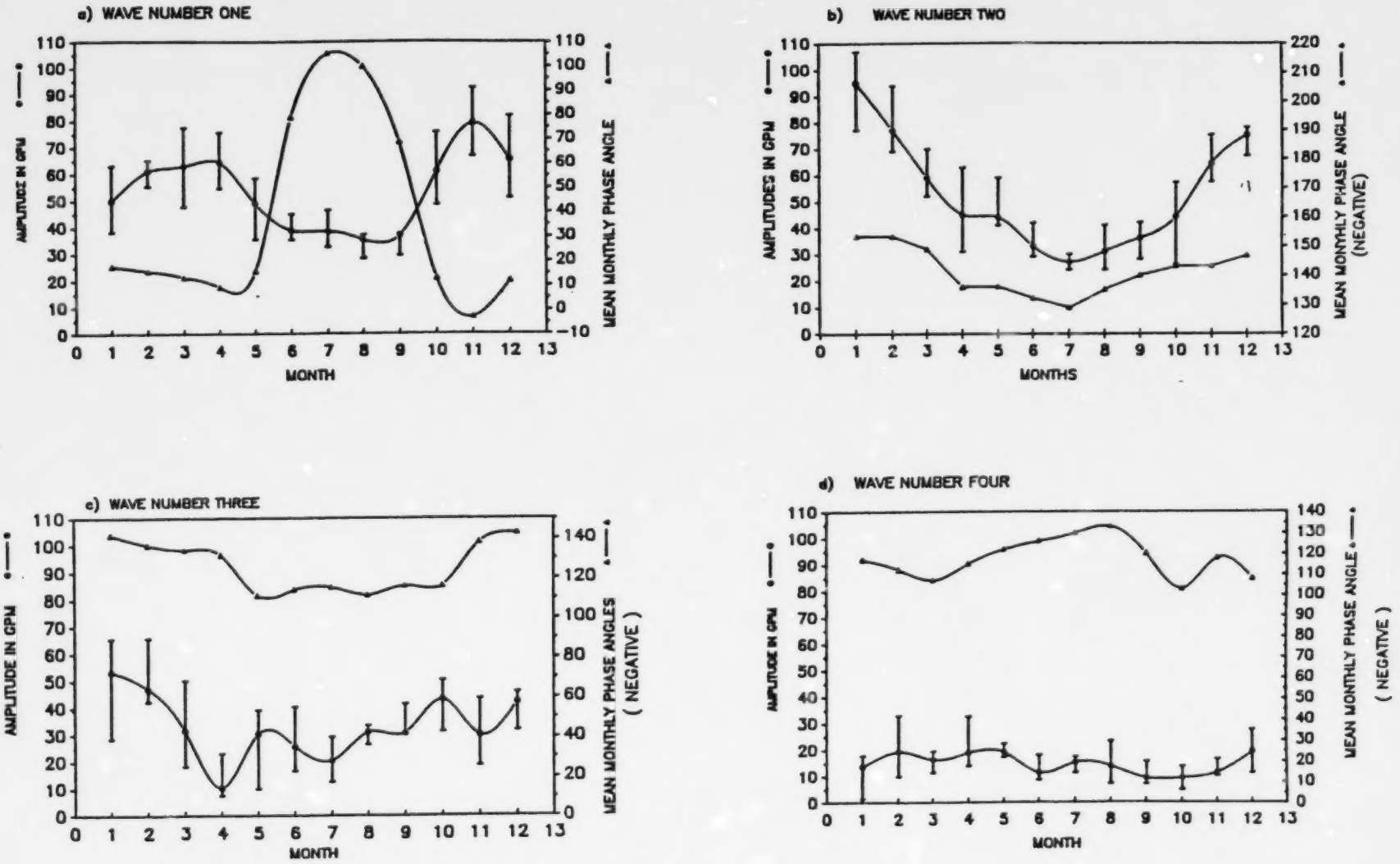
Time period sequence	List of Decade Coverage
1	1946-1955
2	1951-1960
3	1956-1965
4	1961-1970
5	1966-1975
6	1971-1980
7	1976-1983 *

* The last period is only 8-years long

Only those harmonic ridge longitudes are dealt with which are closest to the Mt. Logan meridian. The first four waves alone were considered because wave amplitudes beyond wave number 4 became very small, less than 10 GPM and their contribution to the total variance is less than 5% on the 50 KPa surface.

A summary diagramme illustrates the long term mean amplitudes and phase angles of the first 4 wave components (Figure 5). It has been noticed that the positions of a few outliers could tilt the arithmetic means very much towards their (outlier) values. Therefore following the idea of Bryan (1987), the median positions of amplitudes and phase angles have been given in preference to arithmetic means. Seven values of seven decades were plotted for each month.

Figure 5. Mean Monthly Amplitudes and Phase Angles, Wave Nos 1-4



Maxima, minima and medians of the mean monthly amplitudes and mean monthly phase angles of wave numbers 1-4, at 60°N, 1946-1983

In Figure 5 the scatter of amplitudes is shown in error bar representation. Bar sections for minimum and maximum are shown and the median values define the curve indicated. The scatter of phase angles is not shown, only the 38-year monthly averages. Positive phase angles indicate longitudes east of the Greenwich meridian, and negative values, west of Greenwich. Figure 5 shows that wave number 1 does not develop any ridge near Mt. Logan. The wave number 1 trough is near 160°W during the winter. The amplitudes of wave numbers 1 and 2 are high, those of wave numbers 3 and 4 are much less. However, in January wave number 3 amplitude is greater than wave number 1 at 60°N. In the Mt. Logan region we can consider ridges of importance when they lie between 115°W and 140°W. From April to September, Mt. Logan is influenced by wave number 2. From November to April wave number 3 may be influential, and wave number 4 only during July and August.

It is to be noted that wave number 1 weakens the resultants of wave numbers 2-4 from October to May because the maximum of this wave is positioned almost 180° away from the Mt. Logan meridian (Figure 5). Therefore, wave number 1 is not considered as a likely contributing component to the Mt. Logan precipitation, thus it will be disregarded in the ensuing discussion. However, the other three wave components will be discussed in depth both in this and the next section.

Discussion has been restricted so far to the long-term (38 yr) mean statistics of the first 4 component waves. In the following discussion the time variation of the Fourier statistics is examined within the 38-year period. The long-term averages of the phase angles and amplitudes are broken down into seven decades for the discussion of wave numbers 2-4 and shown in Figures 6-9. The zonal position of the wave maxima in both the phase angle and the amplitude presentation of Figures 6-9 are shaded for each decade near the Mt. Logan region.

These changes were such that the pattern of phase angles of wave number 2 changed during the 1966-1975 decade and the amplitude pattern of the same wave followed a similar trend during 1956-1970 (Figure 6).

The phase angle pattern of wave number 3 is made up of vertical and slanted components. The latter ones slant down from right to left and are quite fragmented (Figure 7). The amplitude pattern is quite consistent until the 1961-1970 decade, then becomes fragmented and slanted from right to left.

The decade mean positions of wave number 4 at Mt. Logan (Figure 8) were restricted to summer seasons and November only until the 1971-1980 decade. From this decade on, wave number 4 appeared in January and March.

Finally, the resultant amplitudes of the harmonics 1 to 4 are shown for each month of every decade at 60°N, 140°W at Mt. Logan. The contour values were rounded and are shown in Figure 9a. The decadal means reveal a consistent maximum in July. Similarly, a consistent July maximum is shown in Figure 9b where the resultant amplitudes of the first 8 harmonics are presented. The consideration of 8 harmonics, instead of four, did not change the isoline values seen in Figure 9a. The resultant contours of these two figures are smoother than the isoline patterns of the component harmonics shown earlier in Figures 6 to 8.

The resultant monthly mean heights of the first 8 principal harmonics for the 50 KPa surface at the Mt. Logan site (Figure 10) reveal more detail than the decadal mean diagrammes do in Figure 9. All three figures agree, in that they have summer maxima, which are centered in July and winter minima in January-February, occasionally in March. The visual appearance of the monthly resultant heights suggest that time series analysis should be run on this data.

Figure 6. Phase Angles and Amplitudes for Wave Number 2 at 60°N, 1946-1983

(a)

DECADE PERIOD	MONTHS											
	1	2	3	4	5	6	7	8	9	10	11	12
1946-1955	153	155	150	131	105	100	130	134	132	134	142	146
1951-1960	152	154	154	136	132	124	135	133	150	145	145	143
1956-1965	153	153	154	143	138	134	123	132	148	147	149	147
1961-1970	153	152	149	143	143	140	127	128	139	138	147	149
1966-1975	158	152	149	138	147	138	129	140	140	150	144	145
1971-1980	154	153	147	131	4	128	134	44	141	140	139	151
1976-1983	147	151	140	133	141	132	134	113	133	137	136	146

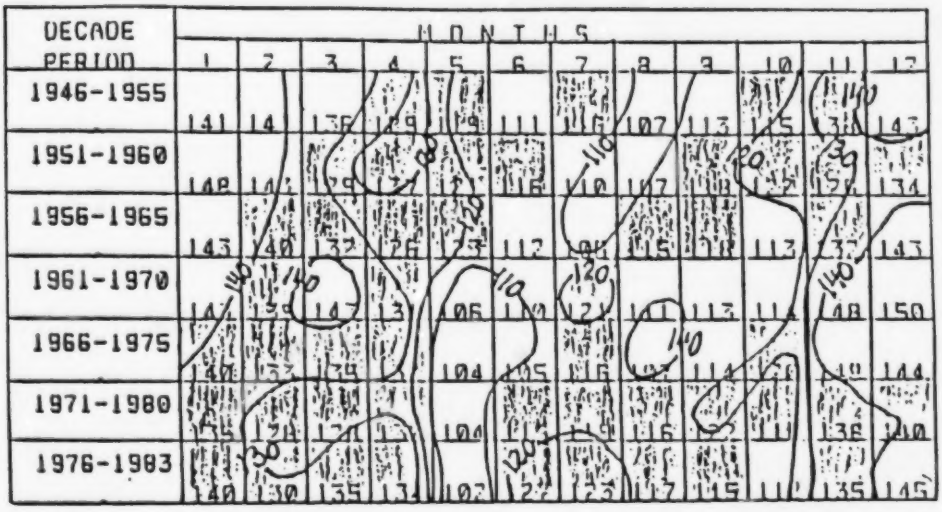
(b)

DECADE PERIOD	MONTHS											
	1	2	3	4	5	6	7	8	9	10	11	12
1946-1955	90	79	52	15	4	36	60	40	33	30	63	75
1951-1960	93	70	59	53	44	33	28	31	28	50	55	78
1956-1965	90	77	64	53	39	39	25	24	36	50	45	66
1961-1970	89	85	57	52	55	60	60	25	42	38	64	67
1966-1975	106	86	99	78	42	31	28	20	36	26	68	60
1971-1980	107	94	70	31	11	9	24	36	37	44	54	62
1976-1983	77	72	70	37	46	50	27	34	33	61	68	76

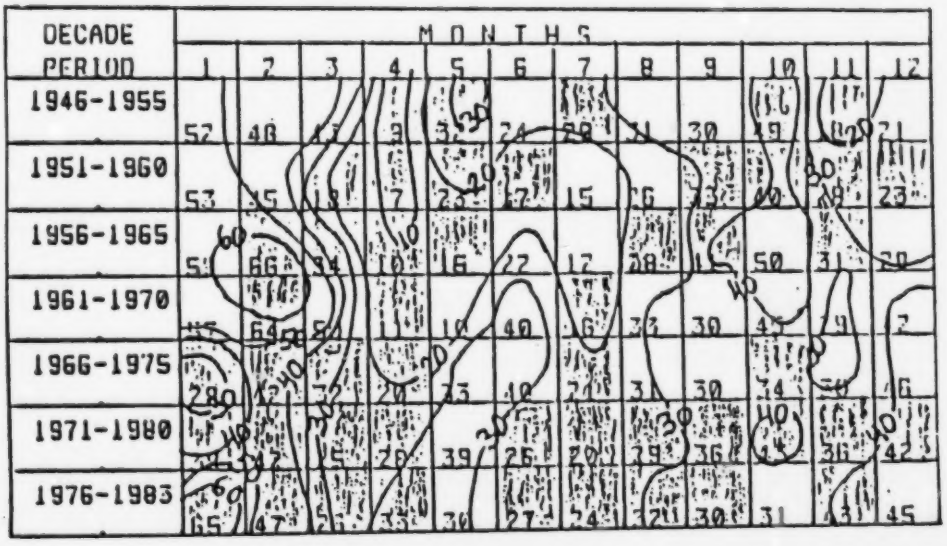
Monthly mean phase angles (a) and amplitudes (b) of wave number 2 at 60°N for 7 decades. Values within the 115°W - 140°W band are shaded.

Figure 7. Phase Angles and Amplitudes for Wave Number 3 at 60°N, 1946-1983

(a)



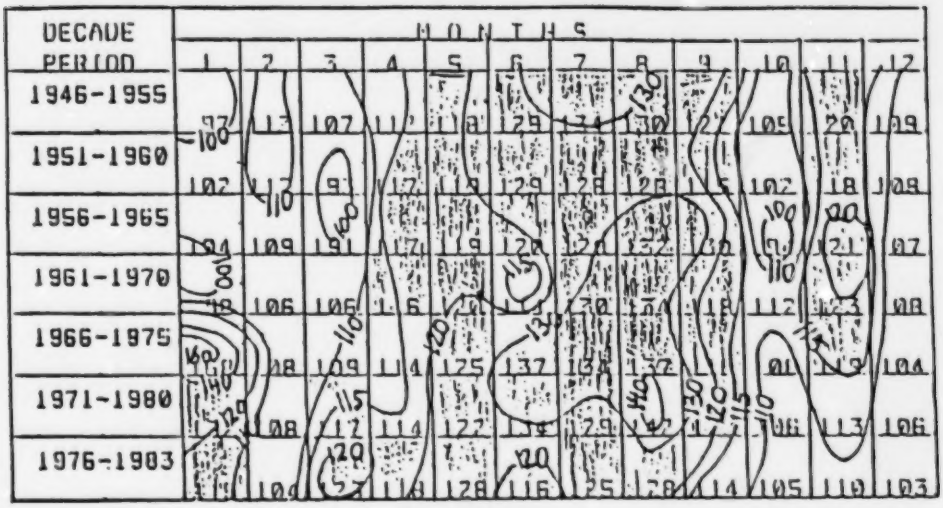
(b)



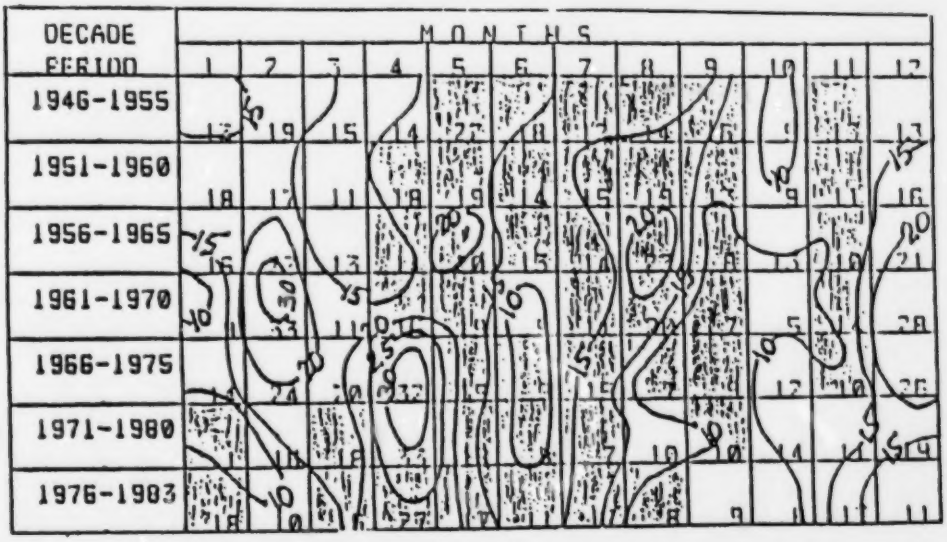
Monthly mean phase angles (a) and amplitudes (b) of wave number 3 at 60°N for 7 decades. Values within the 115°W - 140°W band are shaded.

Figure 8. Phase Angles and Amplitudes for Wave Number 4 at 60°N, 1946-1983

(a)



(b)



Monthly mean phase angles (a) and amplitudes (b) of wave number 4 at 60°N for 7 decades. Values within the 115°W - 140°W band are shaded.

Figure 9. Resultant Amplitudes of the First 8 and 4 Mean Monthly Harmonic Waves

(a)

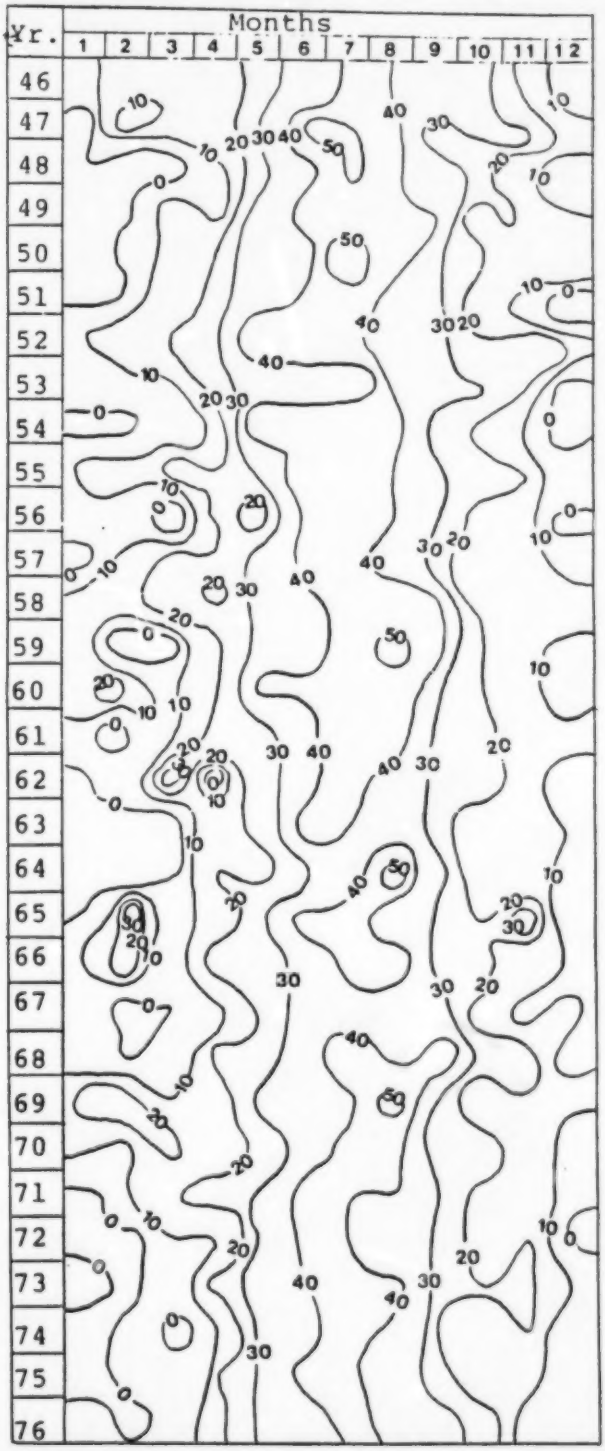
Decade Periods	MONTHS											
	1	2	3	4	5	6	7	8	9	10	11	12
1946-55	14	15	16	17	31	43	47	44	32	13	18	11
1951-60	15	14	14	19	36	41	47	43	30	16	16	11
1956-65	16	13	13	20	32	40	47	44	29	14	19	13
1961-70	15	12	13	18	28	37	47	42	30	12	18	12
1966-75	16	14	12	17	27	37	44	41	29	13	15	09
1971-80	19	14	13	18	27	38	46	42	35	16	15	10
1976-83	19	14	16	18	30	41	49	42	30	21	15	14

(b)

Decade Periods	MONTHS											
	1	2	3	4	5	6	7	8	9	10	11	12
1946-55	14	15	15	17	31	43	46	44	33	14	18	12
1951-60	15	14	14	19	36	42	47	43	31	17	18	12
1956-65	16	13	13	20	32	40	47	44	30	14	19	13
1961-70	14	12	13	18	29	38	48	43	30	18	17	12
1966-75	16	14	12	17	28	38	45	41	29	13	16	09
1971-80	20	14	12	18	28	39	46	42	30	16	16	10
1976-83	18	14	16	18	30	41	49	41	31	22	16	14

The resultant amplitudes of the (a) first 4 mean monthly harmonic waves, and (b) first 8 mean monthly harmonic waves at 60°N latitude, 140°W longitude and for the seven time periods of 1946-1983

Figure 10. Long-term Mean 50 KPa Heights for the Mt. Logan Region



Resultant heights of the first 8 principal harmonics calculated for the 50 KPa geopotential surface at 60°N and 140°W, Mt. Logan, Y.T.

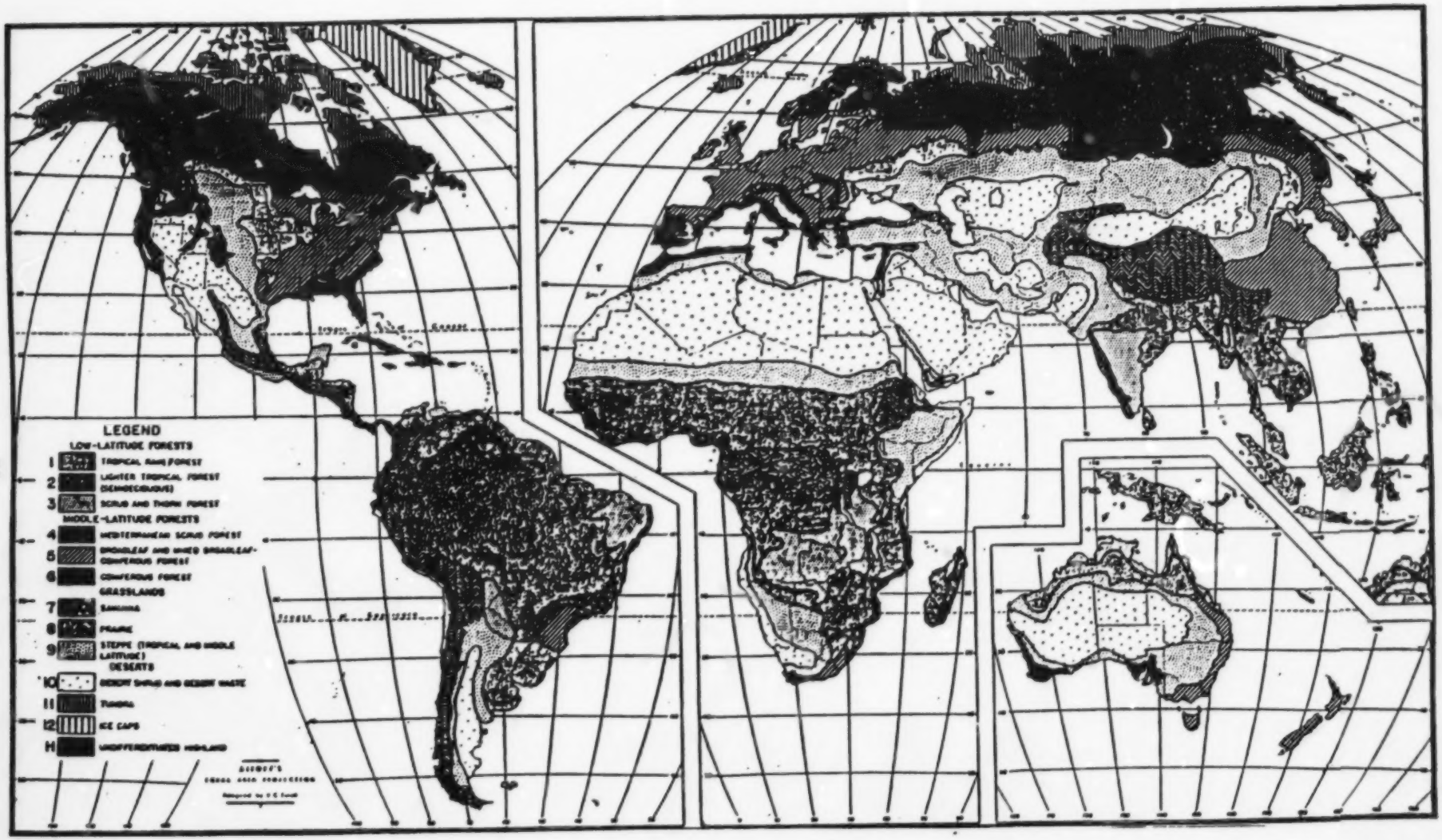
COMPONENT WAVE CONDITIONS OVER THE SOVIET STEPPE AND WOODED-STEPPE REGIONS

In order to study the teleconnection between the net mass balance time series of the Mt. Logan ice core and the U.S.S.R. areal mean precipitation time series from the Steppe and Wooded-Steppe zones, a knowledge of the geographical extent of the U.S.S.R. Steppe zones is required. World vegetation types, which are closely related to climatic zones, are shown in Figure 11 and the Steppe and Forest Steppe zones of the U.S.S.R. relevant to this study are shown in Figure 12 which is taken from Rumney (1968). Figure 12 also shows 21 Russian weather stations that we have identified as being the most likely ones to have been used in the reproduction of an areal mean winter precipitation time series summarized on Table 2 from 21 Russian weather stations (Budyko 1977). We have been unable to obtain information on the stations used or the method of averaging the data. In this study, we use original Russian weather data (U.S. Department of Commerce, 1968) in an attempt to recreate the precipitation curve shown in Budyko (1977).

Table 2: List of U.S.S.R. Meteorological Stations

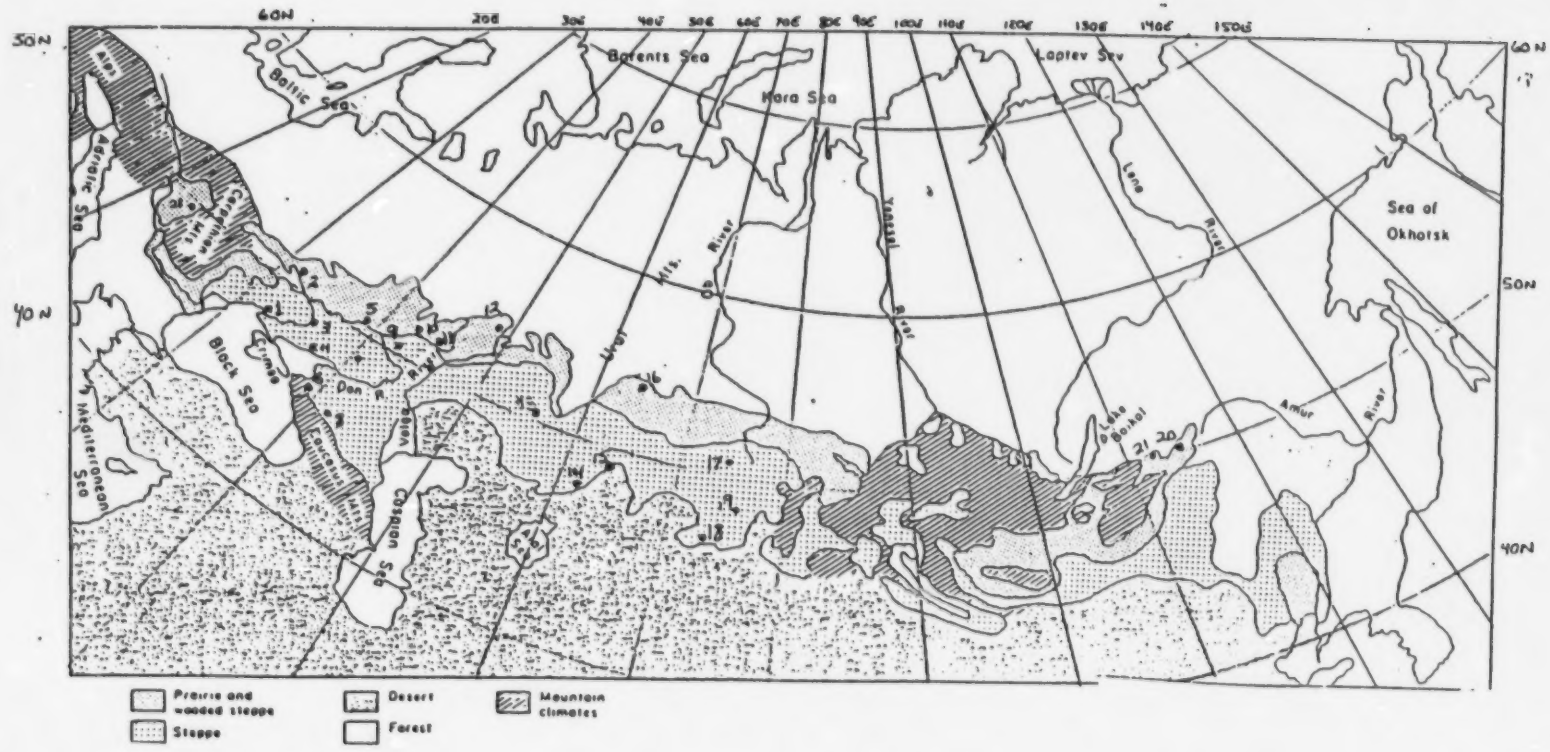
Station	Latitude °N	Longitude °E	Elev. (m)	Years of Record
1. Odessa	46.26	30.46	65.3	1881-1960
2. Kiev	50.27	30.3	182.9	1881-1960
3. Kharkov	49.56	36.17	152	1951-1960
4. Rostov-na	47.15	39.49	77	1951-1960
5. Voronezh	51.42	39.1	164	1951-1960
6. Zaporozhye	47.48	35.15	86	1951-1960
7. Boguchar	49.56	40.34	83	1951-1960
8. Armavir	44.59	41.07	208	1951-1960
9. Tambov	52.44	41.28	139	1951-1960
10. Saratov	51.34	46.02	156	1951-1960
11. Nikdlaewskoe	51.38	45.27	193	1881-1960
12. Kasan	55.45	49.12	80.9	1881-1950
13. Orenburg	51.45	55.06	108.9	1888-1950
14. Kasalinsk	45.46	62.07	66.6	1921-1950
15. Turgay	49.38	63.3	124	1923-1960
16. Swerdlowsk	56.5	60.38	282	1881-1950
17. Akmolinsk	51.08	71.25	353	1923-1950
18. Karaganda	49.48	73.08	555	1951-1960
19. Balkhash	46.54	75.00	423	1951-1960
20. Tchita	52.03	113.29	683	1924-1960
21. Nerchinsky	51.19	119.37	620	1933-1950

Figure 11. Vegetation Types of the World



World distribution of the principal vegetation types. From Climate and Man, 1941, Yearbook of Agriculture as shown by H.J. Critch-field, 1960; General Climatology, Prentice Hall Inc., N.J., 465 p.

Figure 12. Steppe and Wooded Steppe Regions of Eurasia

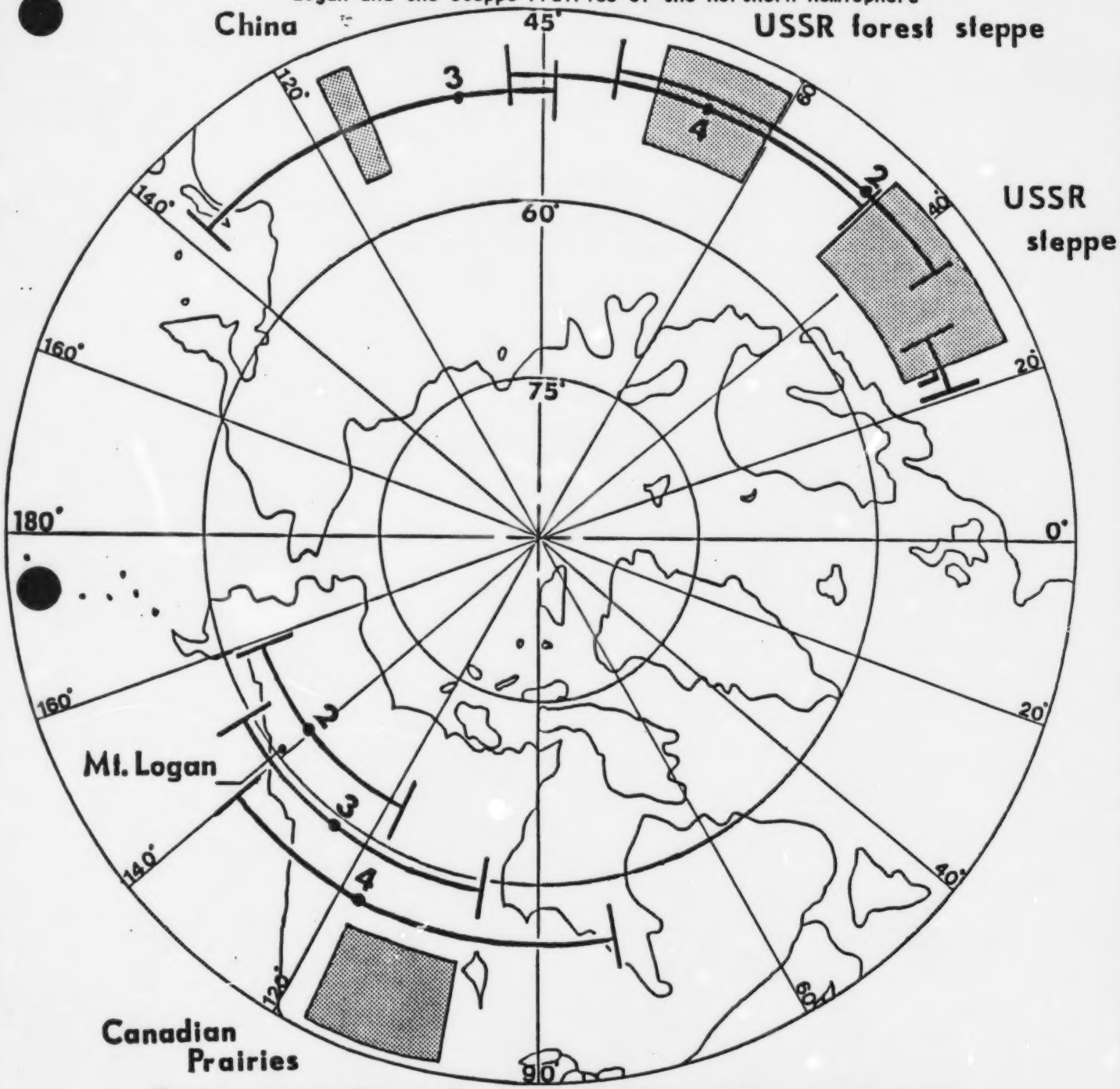


Mid-latitude grasslands in central Eurasia (Rumney, 1968) showing locations of meteorological stations used in this study.

From west to east the median latitudes of the Russian stations are as follows: 49.49°N, 49.43°N, and 52.01°N. Fourier statistics, though not available for these specific latitudes, are available for 50°N, which appears to be a suitable compromise. The long-term median positions and the absolute zonal shifts of the annual long harmonic wave ridges in the vicinity of Mt. Logan and the Steppe-Prairies of the Northern Hemisphere are shown in Figure 13. The error bars of the long wave ridges in the Mt. Logan area are drawn along different latitudes, however, they all refer to 60°N latitude whereas the error bars drawn for the Russian and Chinese Steppe areas refer to 50°N latitude. The long-term monthly relative geographic positions of the first 4 long harmonic wave ridges at the Mt. Logan region and the Russian Steppe zones are shown in Figure 14. Error bar presentation is retained in this figure as well with the exception of the representation of the median positions of the component wave ridges; which are shown with 1 - 4 numerals and indicate the median ridge positions of the respective harmonics which these numbers refer to. At this scale these fragmented areas are only schematically shown. Areas shaded in gray are the zones within which climatological data could be obtained from the World Weather Records. Gaps between the shaded zones are either not supported by climatogical records or are outside the Soviet Union. On the basis of the 40°N contour pattern (of Figure 4), it was expected and later shown that the wave climatology of the median Steppe latitude differed significantly from that of Mt. Logan. The long-term monthly median position of the first four component waves reveal substantial decadal deviations (horizontal bars) in the U.S.S.R. and the Mt. Logan data sets.

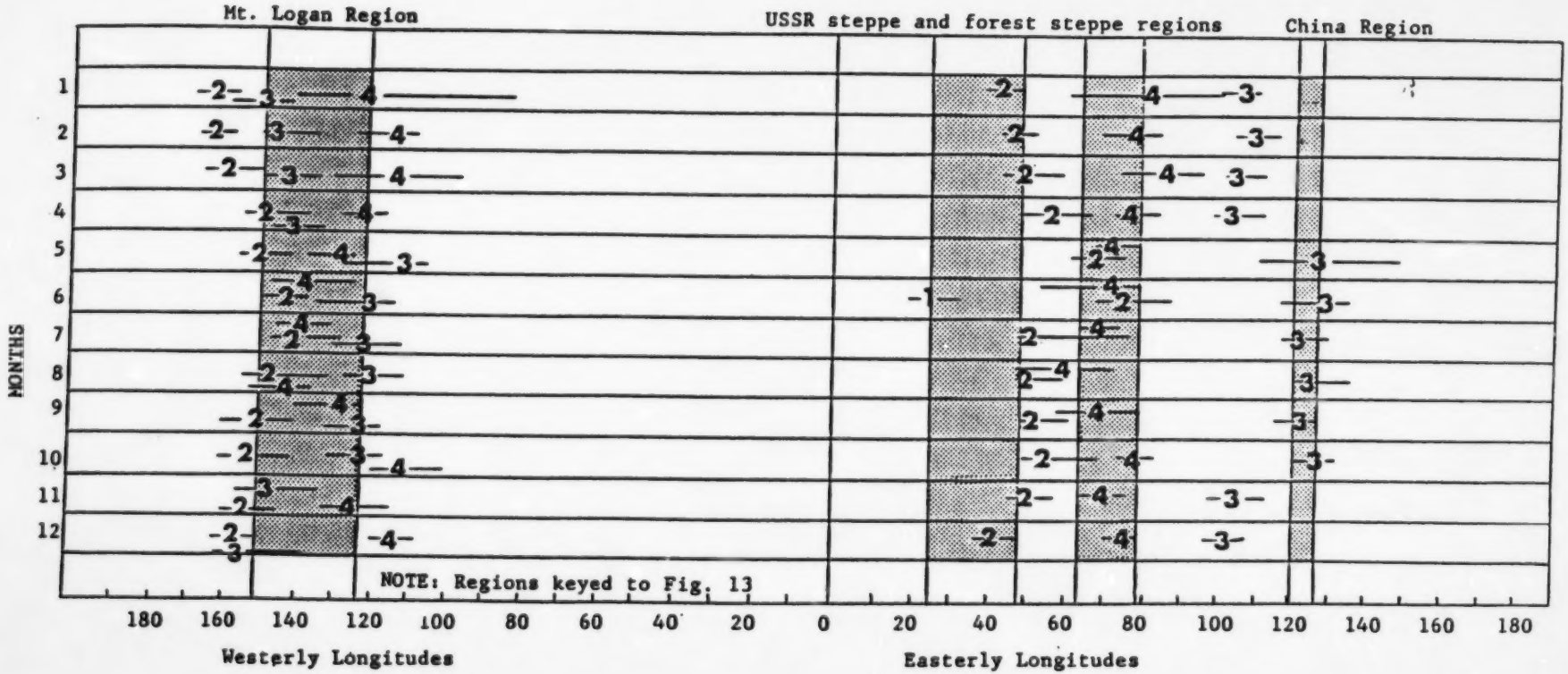
Interpretation of Figure 14 is greatly facilitated if we consider that the Mt. Logan and Prairie region are situated approximately 180° apart from the Russian Steppe zones (Figure 13). This situation suggests the influence of wave numbers 2 and 4 at both the Mt. Logan and the Steppe regions. Figure 14 indeed reveals that the maxima of both wave numbers 2 and 4 coexist in both zones. A maxima of wave number 3 frequently occurs at the Mt. Logan region but the corresponding wave maxima simultaneously occurs only in the most eastern part of the Soviet Steppe belt and China. The European and the West Asian Steppe zones, as with the Mt. Logan region, are dominated by wave numbers 2 and 4.

Figure 13. Situation of the Annual Long Harmonic Waves with Respect to Mt. Logan and the Steppe Prairies of the Northern Hemisphere



The long-term absolute shifts (bars) and median positions (dots) of the harmonic wave ridges: 2, 3 and 4 at Mount Logan, Y.T., and Cana-dian Prairies are derived for 60°N. The wave shifts at the Steppe and the Forest-Steppe regions of U.S.S.R. and China refer to 50°N.

Figure 14. Monthly Mean Distribution of the Long Component Waves with Respect to Mt. Logan and the Steppe-Prairies of the Northern Hemisphere along 2 Latitudes



38 year-mean meridional positions of Numbers 2, 3, and 4 planetary wave ridges at Mt. Logan (Yukon Territory) and the Steppe, Forest-Steppe regions of U.S.S.R. from 1946 to 1983. The centre of the numeric digits refer to the median position of the respective phase angles. The medians were obtained from the 7 mean phase angles of 7 decades. Horizontal lines indicate phase shifts during the 7 decades. Phase angles for Mt. Logan region were calculated along 60°N, whereas for the Russian Steppe zones (in grey) along 50°N latitude.

Since this technical note is only intended as a progress report, no formal conclusions will be offered; rather, we will indicate the direction of our future investigations on this project.

FUTURE WORK

1. The Soviet and other precipitation time series will be updated when the data are made available, and appropriately processed.
2. Formal lagged cross-correlations between the time series will be carried out.
3. Investigation will be made of the inter-annual variation of amplitude and phase angle of the annual mean geometry of the first four Fourier components of the 50 KPa surface. It is possible that variations in this geometry are responsible for modulating the precipitation time series seen in Figure 1. If this is so, then we have strengthened our position in the investigation of the teleconnection. Also, further study of the relationship between blocking and planetary wave dynamics will be carried out.
4. The role of sea-surface temperatures for the North Pacific and the North Atlantic will be examined. Already it has been noticed that the 5-10 year mean SSTs positively correlate with the preciptation time series over certain periods of time. From this perspective, it appears that SST's may be modulating the precipitation, but there is evidently a strong coupling between SST anomlies geometries of planetary waves and regional precipitation. Information in the literature will be researched.

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REFERENCES

Austin, J.F., 1980. The blocking of middle latitude westerly winds by planetary waves. Quarterly Journal of the Royal Meteorological Society, 106(448), 327-350

Benjey, W., 1969. Upper air wind patterns in the St. Elias Mountains of Summer 1965. Icefield Ranges Research Project Scientific Results Vol.1, American Geographical Society and Arctic Institute of North America, 3-16

Bryan, J.G., 1987. Notes for a short course on robust and resistant statistical methods. Presented at the Tenth Conference on Probability and Statistics in Atmospheric Science of the American Meteorological Society, 4-5 October 1987, Edmonton, Alberta, Canada, 104 pp.

Budyko, M.I., 1977. Climatic Changes. Translation by the American Geophysical Union of the Russian Edition, 1974 by Gidrometeoizdat, Leningrad, Printed by Waverly Press Inc., Baltimore, Maryland, 261 pp.

Colucci, S.J., Loesch, A.Z., and Bosart, L.F., 1981. Spectral evolution of a blocking episode and comparison with wave interaction theory. Journal of the Atmospheric Sciences, 38(10), 2092-2111

Egger, J., Metz, W. and Müller, G., 1986. Forcing of planetary-scale blocking anti-cyclones by synoptic-scale eddies. In - Anomalous Atmospheric Flows and Blocking, (Editors), R. Benzi, B. Saltzman and A.C. Win-Nielsen, Advances in Geophysics Vol.29, Academic Press, N.Y., 183-198

Hameed, S., Yeh, W.M., Li, M.T., Cess, R.D. and Wang, W.C., 1983. An analysis of periodicities in the 1470 to 1974 Beijing precipitation record. Geophysical Research Letters, 10(6), 436-439

Harley, W.S., 1980. Northern Hemisphere monthly mean 50 KPa and the 100 KPa height charts. Report No. CL1 1-80, Atmospheric Environment Service, Environment Canada, Downsview, Ontario, 30 pp.

Holdsworth, G., unpublished. Climatic implications from the Mt. Logan ice core. Seminar paper presented at the Canadian Climate Centre, Atmospheric Environment Service, Environment Canada, Downsview, Ontario, March 10, 1987

Knox, J.L., 1982. Atmospheric blocking in the Northern Hemisphere. Canadian Climate Centre Report No.82-2, Atmospheric Environment Service, Environment Canada, Downsview, Ontario, unpublished, 274 pp.

Lindzen, R.S., 1986. Stationary planetary waves, blocking, and interannual variability. In - Anomalous Atmospheric Flows and Blocking, R. Benzi, B. Saltzman and A.C. Win-Nielsen, (Editors), Advances in Geophysics Vol.29, Academic Press, N.Y., 251-273

Namias, J. and Cayan, D.R., 1981. Large-scale air-sea interactions and short-period climatic fluctuations. Science, 214(4523), 869-876

Reiter, E.R., 1983. Teleconnections with tropical precipitation surges. Journal of the Atmospheric Sciences, 40(7), July, 1631-1647

Reiter, E.R. and Westhoff, D., 1981. A planetary wave climatology. Journal of the Atmospheric Sciences, 38(4), April, 732-750

Rumney, G.R., 1968. Climatology and the World's Climates. Macmillan, New York, 656 pp.

Shabbar, A., 1985. AES Experimental Monthly and Seasonal Forecasts. Report No.85-16, Canadian Climate Centre, Atmospheric Environment Service, Environment Canada, Downsview, Ontario, 11 pp.

Shabbar, A. and Knox, J.L., 1987. Harmonics (0 to 8) by month, season, and 10 year mean (with 5 year overlap) of 50 KPa height for the Northern Hemisphere. Unpublished report, Canadian Climate Centre, Atmospheric Environment Service, Environment Canada, Downsview, Ontario

Tung, K.K. and Lindzen, R.S., 1979. A theory of stationary long waves; Part I: a simple theory of blocking. Monthly Weather Review, 107(6), 714-734

U.S. Department of Commerce, 1968. World Weather Records, 1890-1960, Volumes 1-6. Environmental Data Service, Environmental Science Services Administration, U.S. Department of Commerce, Washington, D.C.